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THE VELOCITY-REVERSAL HYPOTHESIS - IMPLICATIONS FOR A MOUNTAINOUS STREAM BED MORPHOLOGY

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ABSTRACT

This paper presents the results of a study of reversal hypothesis phenomena observed within riffles and pool sequences on a 1.1 km long reach of the Skawica-Jalowiecki Stream. The Skawica-Jalowiecki is a flashy mountain stream with an alluvial bed that transports sediment during frequent floods. The study reach is situated just below the border of the Babia-Gora National Park in Polish Carpathians, which provides a good, undisturbed research site. It was found that Q=4.27 m^3s^{-1}, Q=2.43 m^3s^{-1} velocities and shear stresses in pools were highest over riffles during spring floods. It was also observed that unit stream power above the pools was bigger than that found in the riffles.

“The River lifts itself from its long bed. Poised wholly on its dream“

(by Hart Crane, from *The River*.)

Key words: water velocity, shear stresses, stream power, pool, riffle

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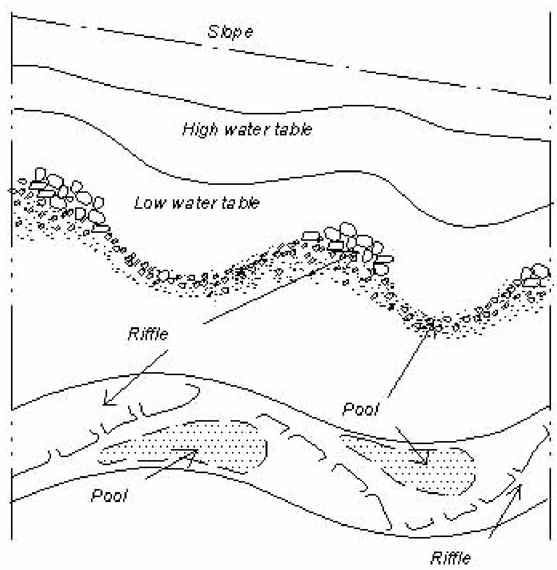
INTRODUCTION

Only a few field investigations cover the origin and behavior of riffle and pool sequences in mountainous gravel streams, and present them as an independent element affecting river-bed shape. Generally speaking, riffles and pools are the characteristic bed forms of gravel-bed channels whose discharge regime permits sediment transport at a typically short-lived dominant flow (Milne 1982) (Fig. 1). Channels with sand-beds have their own morphological river-bed characteristics (Simons and Richardson 1963, Allen 1997), as do small boulder-strewn channels (Miller 1958). These are usually insufficiently competent to sort bed-material into recognizable rhythmic sequences of bed-forms, and are therefore not the subject of this paper.

Fig 1. General sketch of a pool-riffle sequence



The "velocity reversal" (connected with riffle-pool sequences in a river channel) was first reported by Keller (1971). The author noted that as water discharge increases, near-the-bed velocities in pools increase more rapidly than velocities in neighboring riffles. Later, Keller and Melhorn (1978), Siddle (1988), Andrews (1982) and Teisseyre (1984) provided some data to support the velocity-reversal concept, mainly based on forest and small alluvial creeks. Carling (1990), presented a review of the literature both supporting and refuting the hypothesis, and conducted a detailed up-to-date study of "velocity reversal" on the River Severn. Among other comments, he identified an urgent need for field data to support the hypothesis, since any theoretical consideration of the problem is still far too satisfactory. The need for field data is also raised in Carling &Wood (1994), who again use the reversal concept parallel with an HEC-2 model to explain hydraulic data variation. In the present study, the "velocity reversal" hypothesis was tested in the field during a two-year series of measurements under different discharge conditions. The study was undertaken in one of the Polish Carpathian alluvial streams: the Skawica-Jalowiecki Stream, situated in the Beskid Zywiecki Mountains (Fig. 2). The stream is flashy and experiences frequent bedload movement. Situated in the Carpathian flysh, its streambed consists mostly of sandstone and mudstone bed-load pebbles and cobbles. These form a framework, the interstices of which are filled by a matrix of finer sediment. Suspended sediment loads are small and contribute insignificantly to channel morphology. Within the study reach, the Skawica-Jalowiecki cuts through an alluvial bed, mostly Quaternary, Holocene river gravels, sands and mudstones. The upstream reach that was investigated just borders upon a Tertiary, Palaeogene reach, where mica-sandstone, sandstone, mudstone and phyllite predominate. A detailed study of sediment deposited in point and middle bars within the Skawica-Jalowiecki is provided in Radecki-Pawlik (2000, 2002). Many gravel-bedded riffle and pool sequences were noted within the Skawica-Jalowiecki study reach, and of these, two systems were selected for the purpose of"velocity-reversal" investigations. Some basic physical characteristics of Skawica-Jalowiecki catchment research area are presented in Table 1.

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Fig 2. Map of the Skawica-Jalowiecki Stream

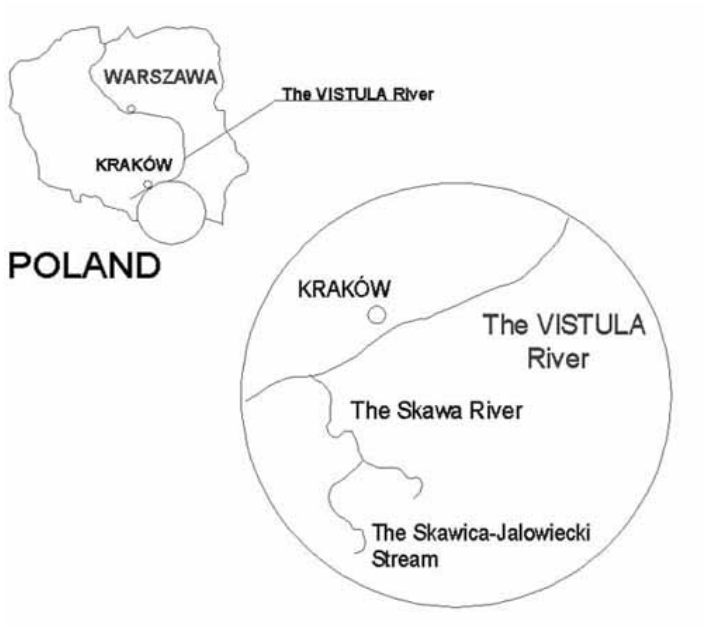

Table 1. Physical characteristics of investigated sites

Variables	The Skawica-Jalowiecki Stream
Precipitation [mm]	1189
Research catchment area [km^2]	19.3
Max. Altitude [m asl]	1130
Min Altitude [m asl]	594
Channel gradient	0.085
Max. Stream width W [m]	16.3
Max. Stream depth D [m]	0.8
W/D ratio (average)	19.6
Minimum annual discharge [$m^3 s^{-1}$]	0.020
Mean annual discharge [$m^3 s^{-1}$]	0.46
Two year flood $Q_{50\%}$ [$m^3 s^{-1}$]	12.62

METHOD

Two pool-riffle sequences (Fig. 3, Phot. 1, Phot. 2, Phot. 3) were selected from several riffles and pools noted along a 1.1 km research reach within the Skawica-Jalowiecki Stream. The two pool-riffle sequences, located in proximity to each other, were the subject of a series of hydrological measurements. These consisted of field velocity measurements (Phot. 4) based on Jarrett's (1990) findings regarding the taking of velocity profiles in mountain stream cross-sections. Gordon & others (1992) and Bergeron & Abraham's (1992) methods were then applied to the field data, and shear velocity V_* values for pools and riffles were calculated from the velocity profiles obtained near-to-river-bed. Finally, shear stress τ values were calculated from:

$$\tau = V_*^2 \rho \text{ [N m}^{-2}\text{]}$$

where: ρ - water density [kg m^{-3}], τ - shear stress [N m^{-2}]
and V_* - shear velocity [m s^{-1}].
To determine the stream power values, Teisseyre's method (1984) was applied:

$$\Omega = \gamma Q E_t \text{ [W]}$$

where: γ - specific weight [N m^{-3}], Q - water discharge [$m^3 s^{-1}$], V - mean velocity [m s^{-1}], g - acceleration [m s^2], h- mean water depth [m] and $E_t = V^2 / 2g + h$ [m] - energy height.
Unit stream power ω was calculated following Carling (1990):

$$\omega = \Omega / A \text{ [W m}^{-2}\text{]}$$

where: A is a cross-section area [m^2].

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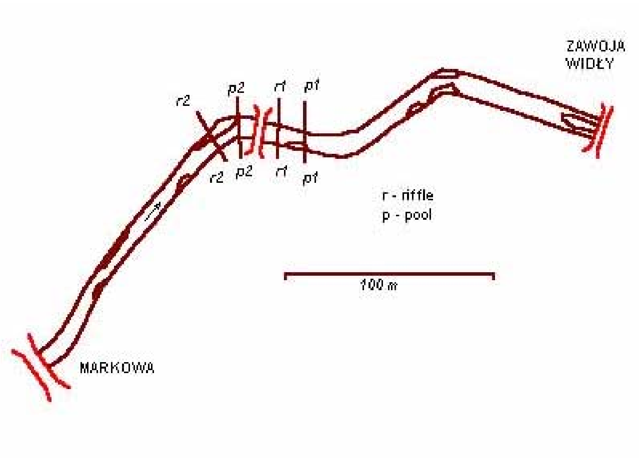
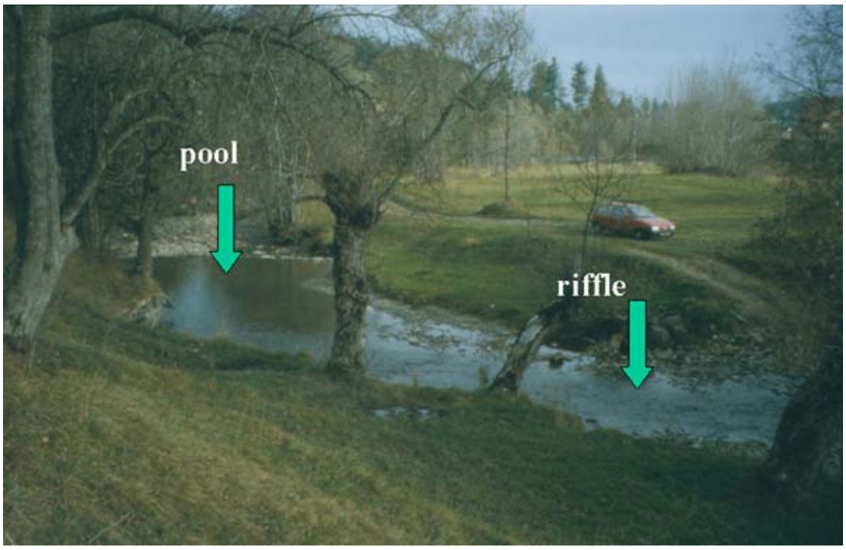
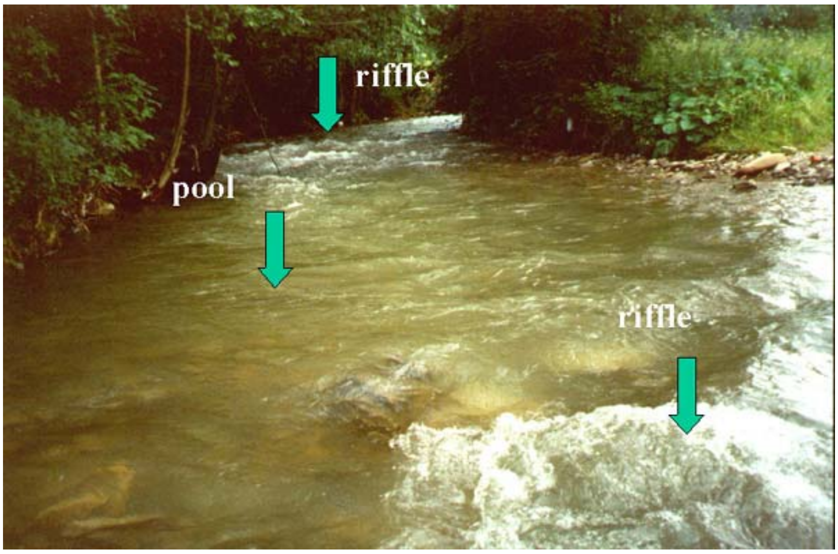
Fig. 3. Situation of the research area



Phot. 1. General bird-eye view of riffle-pool sequence r1-p1, November 1999



Phot. 2. Riffles and a pool: sequence r2-p2 and riffle r1, July 2001



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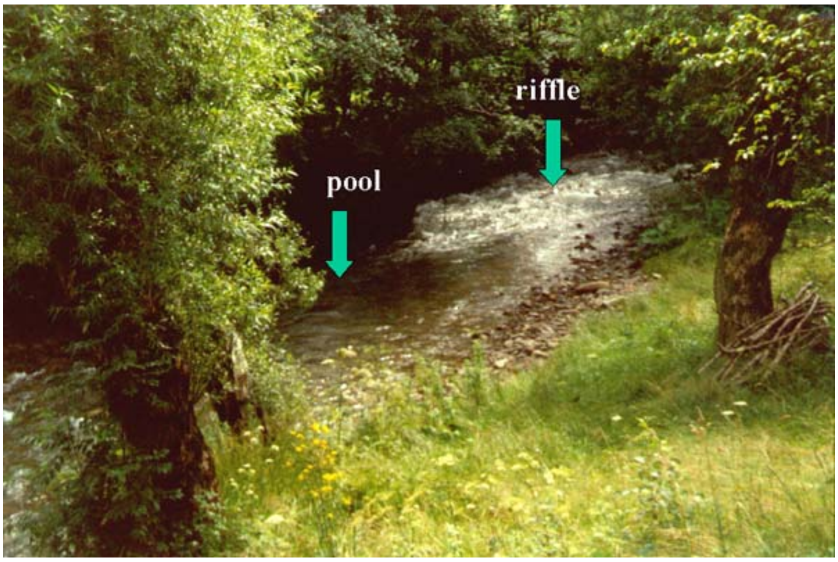
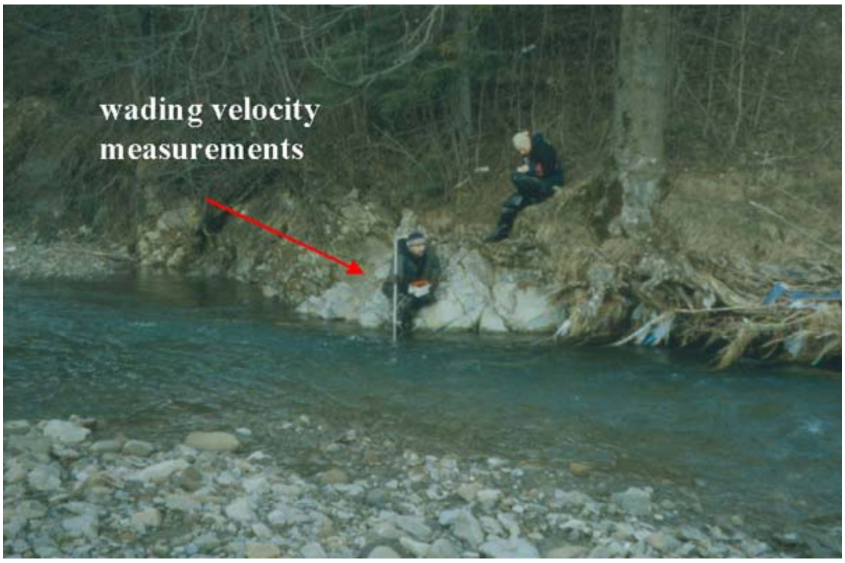
Phot. 3. Riffle and pool sequence r2-p2, June 2000



Phot. 4. Wading measurements of the vertical velocity profiles. measurements within a pool, March 2000



Bed-load sediment deposited within pools and on riffles was also collected. The technique of sampling described by Church, McLean and Wolcot [1987] was applied. Samples were collected from a homogeneous body of sediment, so as not to combine them with distinct surface material. Next, a sieving analysis for coarse grains was carried out by hand in the field, using round-mesh sieves [Michalik 1990].

RESULTS AND DISCUSSION

The results of velocity profile measurements taken within pools and over riffles (Fig. 4), and of data calculations using the equations described in the Method section are presented in Table 2. Gravel grain-size data from pools and riffles sampled just after flooding in 2001 is presented in Table 3.

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Fig. 4. Examples of velocity profiles for riffles and pool sequences.
Abbreviations used: b-riffle, p-pool

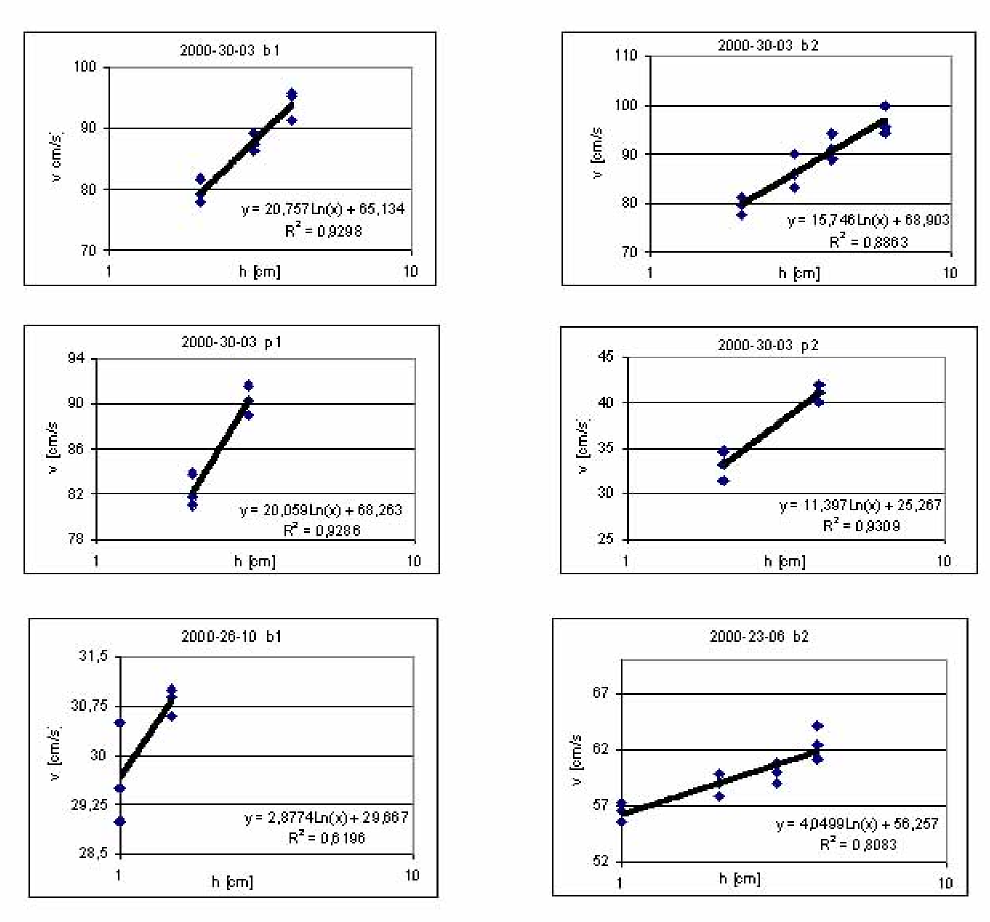

Fig. 4. cont.

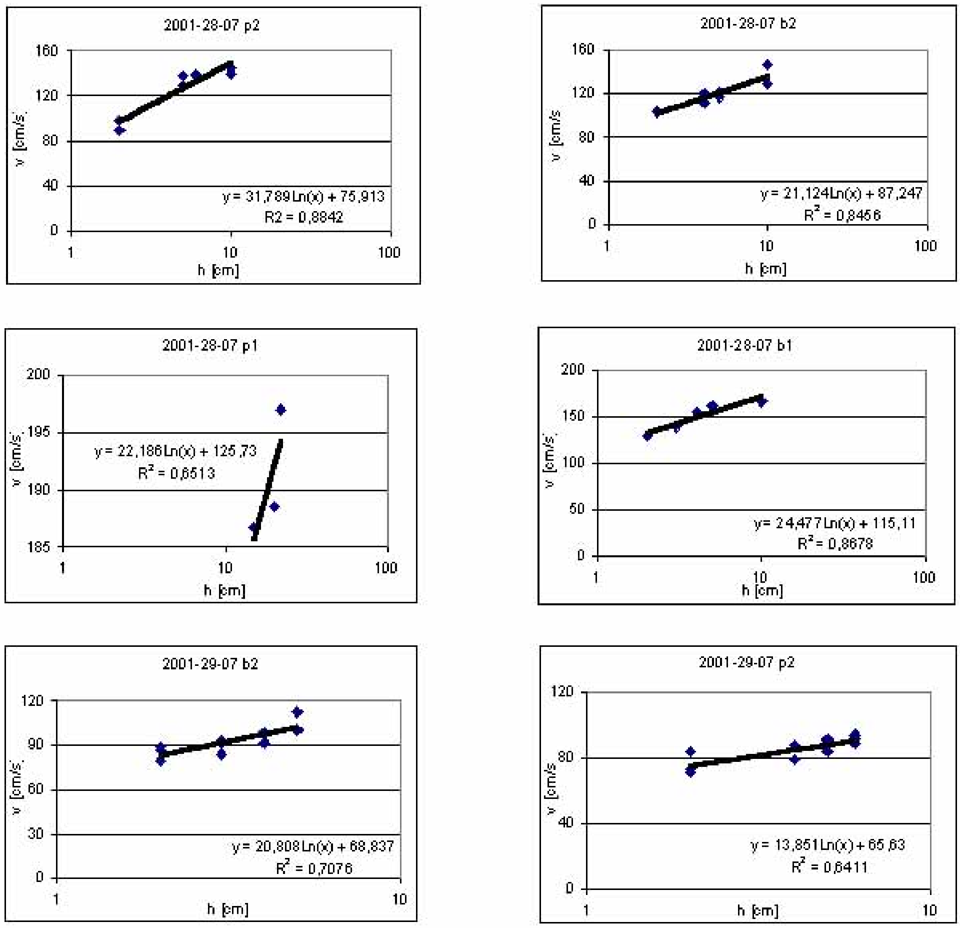

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Table 2. Hydraulics field data results summary

Date and sequence name	Shear velocity (V_*) [$m \cdot s^{-1}$]	Shear stress (τ) [$N \cdot m^{-2}$]	Stream power (Ω) [W]	Unit stream power (ω) [$W \cdot m^{-2}$]	Water discharge (Q) [$m^3 \cdot s^{-1}$]
6.11.1999					
R1	0.032	1.05	529	1 059	0.34
P1	0.006	0.038	1 206	837	0.34
R2	0.023	0.53	310	968	0.34
P2	0.021	0.44	891	781	0.34
30.03.2000					
R1	0.036	1.29	8 128	5 724	1.04
P1	0.040	1.225	10 535	5 852	1.04
R2	0.027	0.73	1 632	2 511	1.04
P2	0.019	0.37	4 804	2 426	1.04
23.06.2000					
R1	0.008	0.069	357	793	0.28
P1	0.006	0.034	1 046	757	0.28
R2	0.006	0.039	449	801	0.28
P2	0.005	0.023	825	763	0.28
26.10.2000					
R1	0.005	0.024	100.6	544.0	0.19
P1	0.004	0.017	562.1	535.2	0.19
R2	0.005	0.025	133.9	531.3	0.19
P2	0.004	0.018	559.1	532.5	0.19
28.07.2001					
R1	0.042	1.812	24020	5474	4.27
P1	0.038	1.477	60092	6928	4.27
R2	0.037	1.349	22950	5216	4.27
P2	0.055	3.056	34722	6677	4.27
29.07.2001					
R1	0.018	0.35	10423	4571	2.43
P1	0.020	0.41	20829	4843	2.43
R2	0.036	1.308	9842	3075	2.43
P2	0.024	0.59	13562	3726	2.43

Table 3. Characteristic grain size dimensions within the riffle and pool sequences

Measuring point		d_{16} [mm]	d_{50} [mm]	d_{84} [mm]
Sequence R1-P1	R1	17	40	82
	P1	35	70	110
Sequence R2-P2	R2	18	42	130
	P2	30	52	67

The velocity results show that the average velocity and near-bed shear velocity measured in the field was greater in pools than over the riffles during flood conditions in July 2001. As well, a tendency towards equalisation of the values of some hydraulic variables was noted when stream discharge increased in March 2000 (when the measured discharge was still three times bigger than the mean annual discharge). Within the pools where the reversal phenomenon was noted, unit stream power was bigger than on the upstream riffle. Also, total stream power was larger in pools. Generally, unit stream power increased as shear stress increased (Fig. 5). At the same time, shear stress above riffles were much more smaller then those within pools (P2R2 for Q=4.27 m^3/sec) (Fig. 6).

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Fig. 5. Dependence of the unit stream power on shear stresses and water depth values

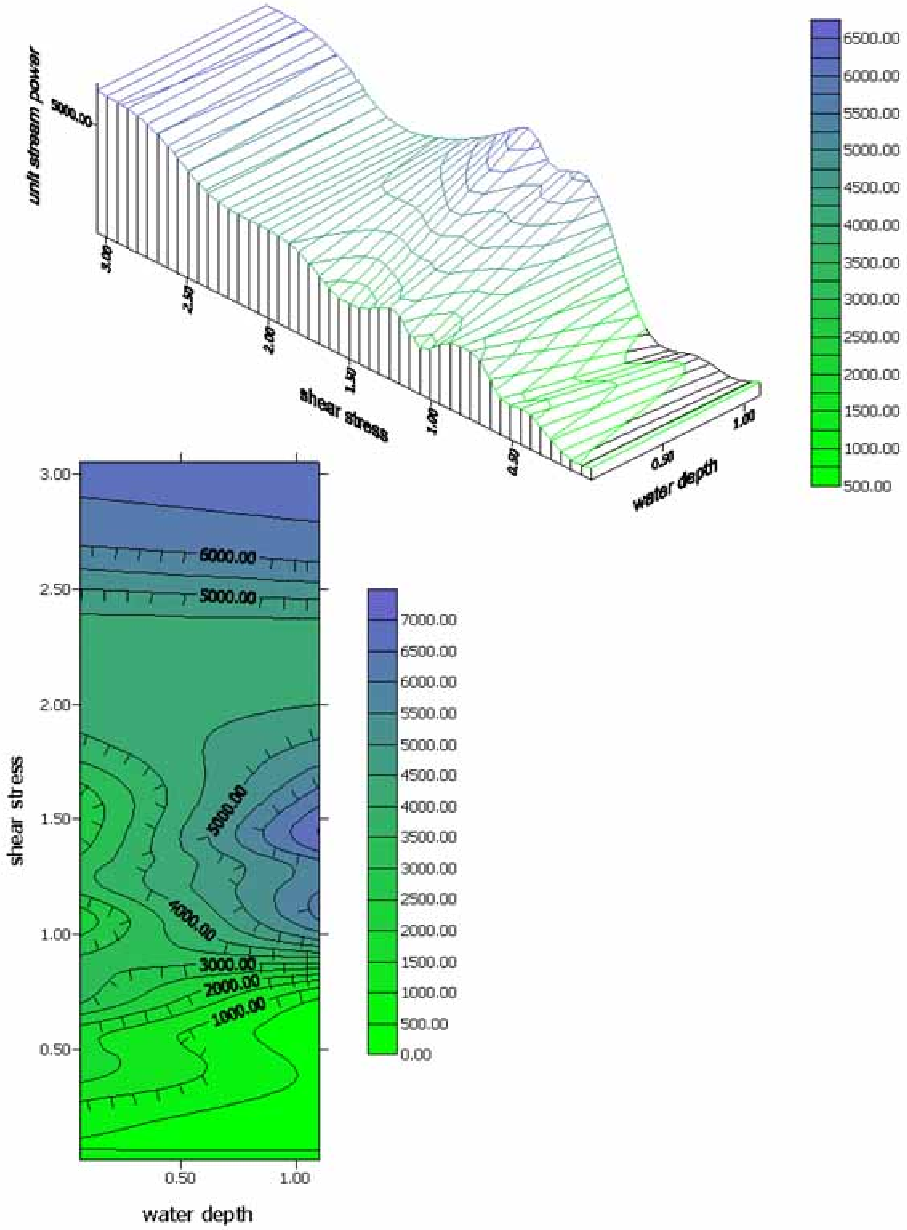
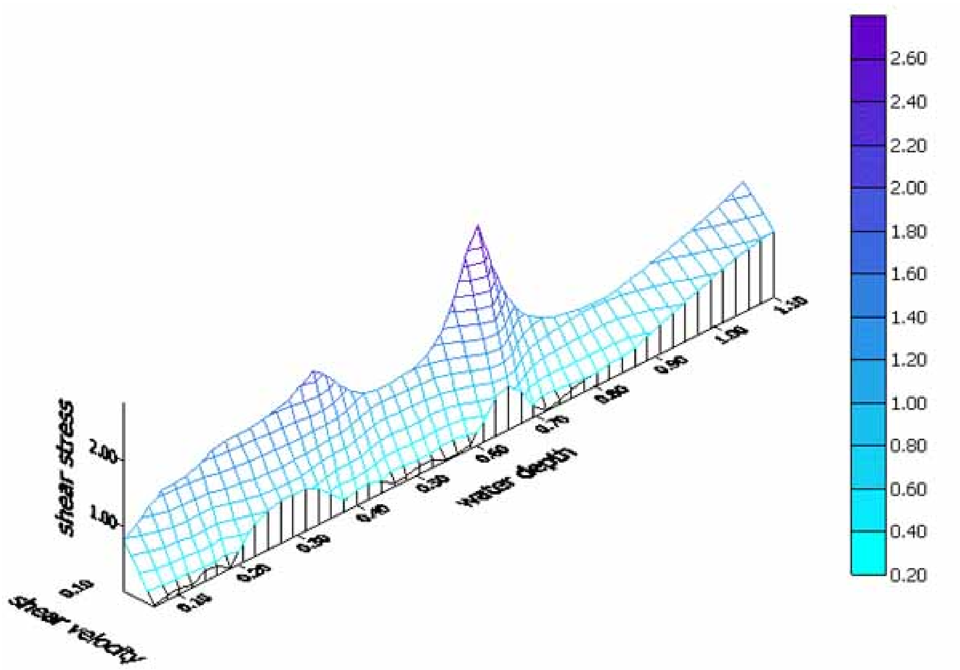


Fig. 6. Dependence of shear stresses and shear velocity on water depth



With regard to the data on velocity, shear stress, and unit stream power, it was noted that under low discharge conditions (below annual mean), fine sediment can be washed out from riffles and deposited within pools. This situation changes under annual mean flow when pools are washed out with fine sediment because of the reversal velocity phenomena. This is clearly seen when analysing the data presented in Table 3, where nearly all characteristic grain-size dimensions in pools measured just after flooding in July 2001 exceeded those measured within riffles. This means that the sediment in pools sediment is coarser than that which built the riffles.

These changes in hydraulic conditions assure the stabilisation of the whole riffle-pool sequence system. This lasts until an over-bankfull or catastrophic flood situation occurs, which changes the whole streambed and/or flood plain system, resulting in the growth of a new system of riffles and pools.

CONCLUSIONS

1. Reversal velocity phenomena in a mountain stream occurred when the mean annual discharge was exceeded by a factor of nearly 10.
2. Unit stream power and total stream power within the pool where the reversal phenomena occurred was considerably bigger than on the upstream riffle. Unit stream power is directly dependent on shear stress value.
3. Under reversal velocity conditions, shear velocities and shear stress values within pools exceeded those over the riffles.
4. Generally, under low flow conditions (hydrological drought), shear velocity and shear stress within pools and riffles tended to equalize.
5. Under mean annual flow conditions, the most significant differences noted related to stream power, unit stream power and shear stress value.
6. During annual flooding and/or nearly bankfull conditions, pools were washed out with fine sediment, which is normally deposited under low flow conditions. Sediment deposited in pools after floods is coarser than this, resulting in the growth of riffles. In this manner, the sequence riffle-pool maintains its stability. The key factor is the over bank flow, which alters the geomorphological status quo of the stream bed (and sometimes the entire flood plain.

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